

# General considerations on the illumination of galactic nebulae.

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The interpretation of observations over different wavelength domains, which now exist over a large fraction of the sky, will be used to determine relationships between a nebula and its' illuminating source.

The illuminating source of a high latitude nebula must be behind the cloud and e.g. at close angular distance. It is either a point source behind the nebula or the average radiation field created by all the background stars. In the latter case it is possible to estimate the maximum surface brightness a nebula can reach. Illumination by the galactic plane is always negligible in up to date observations. The red color of some nebulae, when they are not HII regions, is more likely to be due to large column densities than to an emission process.

Concerning interstellar grain properties, the same data will be used to support the well known property that grains scatter starlight in forward direction.

## 1 Introduction

The aim of the paper is to use the complementarity between different sky surveys to derive conclusions concerning the scattering of starlight in the galaxy. General and qualitative analysis of the data will lead to remarkable links between a nebula and its' illuminating source.

Section 2 presents the data to be discussed in the paper. Section 3 recalls existing interpretations of the origin of the light scattered by high latitude

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nebulae, and on the red color of some nebulae. These interpretations raise questions which will be addressed in section 4. From this section to section 11 on, I will arrive at the different results of the paper. Two applications are discussed in sections 8 and 9. The results are summarized in the conclusion.

## 2 Data

### 2.1 *Palomar optical sky survey*

The most representative and complete existing data set of interstellar dust optical emission is the Palomar plates for the Northern hemisphere and ESO plates for the Southern sky. Palomar images in the  $B$  and  $R$  bands have a sensitivity of  $27 \text{ Mjy/arcsec}^2$  and a resolution of  $2''$ .

Optical interstellar features on the plates have been classified by Lynds in 2 papers, ‘Catalog of Dark nebulae’ [9] and ‘Catalog of Bright nebulae’ [10].

Lynds’ dark nebulae (LDN) are highly extinguished areas of sky, many of which correspond to molecular clouds (Magnani et al [11], Lee & Myers [7] and references therein). The important extinction of these regions is due to the absorption of starlight by interstellar grains.

LDNs are spread all over the sky, at all galactic latitudes (Lynds [9]). The number of LDNs, of course, decreases when moving away from the galactic plane. Most LDNs are concentrated at  $|b| < 10$ , but many are still observed up to  $|b| = 25$ . Lynds’ search of LDNs is limited to  $|b| < 40$ .

Bright nebulae are seen in emission on Palomar plates, either in  $B$ , or  $R$ , or both bands. Like dark nebulae they usually have a small surface coverage ( $< 1^\circ^2$ ). Lynds’ bright nebulae (LBN) are concentrated in the Galactic plane, but are found up to the limit of completeness of her catalog,  $|b| = 40$ . Lynds’ classification of bright nebulae involves various criteria among which are color and surface brightness. Bright nebulae span a wide range of  $B - R$  colors, from completely blue to completely red.

### 2.2 *Magnani et al. search for high galactic latitude molecular gas*

Magnani et al. [11] made a systematic search for CO in Palomar extinguished regions at high latitude ( $|b| > 25$ ). They detected CO in 133 of 488 observed positions. The regions where CO was detected were grouped into 35 separate large complexes (MBM complexes). The average distance to the sun of those

complexes was estimated to be  $\sim 100$  pc (Magnani & de Vries [12]). Most of MBM complexes have some Lynds bright nebula associated with them: six blue nebulae, ten deemed of equal brightness in both  $R$  and  $B$  plates, four brighter on red plates and four visible on red plates only. Remarkably, the CO emission does not systematically coincide with the LBNs. In other words, there is dense material which does not scatter starlight at optical wavelengths at a level detectable by the Palomar survey.

### 2.3 *MCLD123.5+24.9*

I will also mention the optical images obtained at Kitt Peak Observatory by Roc Cutri and Frédéric Zagury. The  $I$  image of the  $1^\circ \times 1^\circ$  field is presented here (figure 1). This field can be perceived on Palomar plates, but with far less detail than in our images. Zagury, Boulanger & Banchet [21] (hereafter paper I) have shown that, despite the presence of local red filaments across the field, all the optical emission of MCLD123.5+24.9 is well explained by normal scattering processes and illumination by the North star,  $1^\circ$  away.

Falgarone et al. [2] have mapped in molecular lines the area inside the rectangle shown in figure 1. Their study reveals high densities,  $n_{H_2} \gg$  a few  $10^3 \text{ cm}^{-3}$ , and column densities in the feature of high extinction within the rectangle. Densities increase toward the central and most extinguished parts. The dense core is completely extinguished in the  $B$  band (figure 2 of paper I) and has a definite red color since its' densest part remain bright in the  $I$ -band and, but to a lesser extent, in the  $R$ -band.

MCLD123.5+24.9 is centered at  $l = 123.5$  and  $b = 24.9$ . It is estimated to be  $\sim 120$  pc to the sun (paper I), which is in accordance with the average distance estimate of high latitude clouds due to Magnani & de Vries [12].

### 2.4 *IRAS whole sky survey*

The IRAS sky survey has revealed large scale structures which HLN and MBM complexes are part of. It has also evidenced the complex structure of galactic cirrus. This structure is also perceived at a scale 100 times smaller than reached by IRAS in the optical emission of MCLD123.5+24.9 (figure 1).

The  $100 \mu\text{m}$  emission of interstellar matter is the thermal emission of the same large grains which scatter starlight in the optical. When a cloud is illuminated by a source of light, there is a very good similarity between the optical image of the cloud and the IRAS  $100 \mu\text{m}$  image of its' infrared emission (figure 2 of paper I).

Fig. 1. *I* band image of MCLD123.5+24.9. The resolution is  $2''$ . The field is  $\sim 1^\circ \times 1^\circ$ . North is at the upper edge and East at the left edge of the image. Polaris is  $1^\circ$  North to the field. The extinct region seen in absorption, and often mentioned in the text is enclosed in the rectangle. This image is discussed in Zagury, Boulanger and Banchet [21].

### 3 A review of current hypothesis concerning the color and illumination of HLN

Many studies of nebulae have based their analysis on the comparison of the color of the nebulae and that of the illuminating source. Lynds uses the difference in color between nebulae to distinguish ‘reflection nebulae’, ‘purely emitting regions’ and ‘transition nebulae’, which conforms to the idea that scattering should turn the emission to blue, because dust scatters blue light more efficiently than red light. According to Lynds, the ‘blue’ emission of reflection nebulae should be attributed to the scattering of starlight, while the red regions arise from some emission line. The same idea is taken up and furthered in more recent studies. It leads to the notion of Extended Red Emission (ERE) (see Gordon, Witt and Friedmann [3] and Leinert et al. [8] for a review).

The color of a nebula depends on its’ optical depth and on the color of the illuminating radiation field. Of course, the latter needs to be unambiguously identified. The problem of the illuminating source of the blue high latitude nebulae was first quantitatively addressed by Sandage [14]. In this paper Sandage shows that a high latitude cloud of low column density in which grains isotropically scatter starlight will be seen on the Palomar plates with a surface brightness of magnitude close to the magnitude observed for the HLN. Like it was already suggested by Lynds [10], Sandage [14] and Maggani et al. [11] attribute the blue HLN of the Palomar plates to dusty nebulae reflecting the light of the galactic plane.

Stark [15] tried to improve Sandage’s model and included forward scattering in his Monte Carlo simulations. A look at figure 9 of Stark’s paper shows that the HLN surface brightness would increase the surface brightness given in Sandage by  $3 \text{ mag/arcsec}^2$ , making HLN undetectable at Palomar sensitivity.

Some authors (Guhathakurta & Tyson [4], Guhathakurta & Cutri [5]) have used Sandage’s proposal as a basis for their affirmation that red high latitude nebulosities ‘produce’ ERE. According to these authors, high latitude clouds are low column density clouds reflecting the light of the galactic plane. With such an illuminating source, the observed color of the clouds is too red to be explained by scattering only. It implies an emission process which occurs within the clouds from the red to the near infrared.

#### 4 The illumination source of high latitude nebulae.

If HLN's are indeed reflecting the light from the galactic plane, which is 'everywhere, all the time' (Sandage [14]), how is it that the light scattered by most dense clouds detected in CO by Magnani et al. [11] is not observed on the Palomar plates? Why is the high density and high column density feature of figure 1 seen in absorption in the  $B$  band?

At the time of Sandage's paper IRAS had not yet been launched and HLN's could be thought to represent a large part of existing interstellar high latitude clouds. Since the IRAS survey, we know that HLN's are a very small fraction of infrared cirrus. If HLN's reflect the Galactic plane's light, we expect a much larger fraction of cirrus clouds to be bright in the  $B$  and/or  $R$  bands. Why do HLN's represent only a small part of the cirrus?

These questions call for several conclusions.

A first conclusion is that HLN's are never illuminated by the galactic plane. Most HLC's are in the solar neighborhood. Viewed from earth, they occupy comparable positions in regard of the light they reflect from the galactic plane. If the galactic plane provides the illumination of one high latitude nebulosity it will, as noted by Sandage [14], similarly illuminate all high latitude clouds and explain the surface brightness of all HLN's. Hence, if a low column density medium reflects the light from the Galactic plane at a level detectable to Palomar sensitivity, a much larger fraction of the HLC's should appear on the Palomar plates. This already indicates that the galactic plane is unlikely to be the illuminating source of HLN's.

Furthermore, if the galactic plane is the illuminating source of low column density HLN's, higher surface brightness is also expected from the reflection by the high column density parts of the infrared cirrus. Since high latitude dark nebulae above the galactic plane are completely extinguished (LDN's, MBM dark clouds, the dark feature in MCLD123.5+24.9), the source of light of HLN's cannot be on the same side as the observer. It has to be behind the nebulae.

Secondly, interstellar grains must strongly scatter light in forward direction. This is of course known since Henyey & Greenstein [6]. It can also be uncovered from Sandage's calculations since, in case of near isotropic scattering, high latitude cirrus would be detectable at Palomar sensitivity. We can assume there is an angle of scattering  $\varphi_f \ll \pi/2$  within which most photons are certainly deviated from their initial trajectory, after being scattered by interstellar grains.

Hence, the illuminating source of an HLN must be behind and, because of

forward scattering, at close angular distance from the nebula. This is confirmed by the observations: all bright nebulae mentioned in literature are at most a few tens of arcminute from their illuminating star.

It is important to remark that the low column density approximation which is usually made to estimate the surface brightness of a nebula is probably not suitable to describe bright nebulae. Contrary to this hypothesis, the most general case should be that a cloud is visible because it has sufficient column density to scatter enough starlight to be detected: its optical depth should in general be close to 1. This is the case for MCLD123.5+24.9 where too low column density regions have little emission and where high density clumps are seen in absorption. In between, regions for which the optical depth gives maximum surface brightness are luminous on the image (paper I). These regions are not the same for the *B*-band than for the *R*-band or for the *I*-band. Since cirrus are known for their small scale structure and for experiencing large ranges of column densities, the same should generally be held for all cirrus.

Different types of background illuminating sources can be thought of for the illumination of an HLN. They are reviewed in the following section.

## 5 The possible illuminating sources of nebulae

As a consequence of section 4, high latitude nebulae seen in emission (HLNs) should be illuminated by a background source. The source radiation field can be of 3 different types:

- (i) A radiation field whose source of light comes from one or a few background point sources (e.g. bright stars). The number of possible illuminating sources of a cloud decreases when moving away from the Galactic plane which renders the identification easier.
- (ii) Multi-directional light sources, none of which dominate the others. This is the case where all background stars contribute to the cloud illumination. For purposes of calculation, the radiation field in one direction can be approximated by an average intensity per unit solid angle ( $\sigma$ ).
- (iii) The radiation field is isotropic (at least for directions within  $\varphi_f$ ).

Case iii cannot produce any optical emission. Each scattered photon from a direction  $\varphi_1$  to a direction  $\varphi_2$  will be replaced by a photon scattered from  $\varphi_2$  to  $\varphi_1$ . Pixels looking outside the cloud will receive more photons than pixels inside the cloud due to absorption. The cloud will be seen in absorption. Whatever the radiation field is at the cloud location, only that part which presents some kind of anisotropy should be taken into account to explain the optical emission of an interstellar cloud. In sections 6 and 7, cases i and ii will

be investigated in further detail.

## 6 Nebulae illuminated by a background point source

In general, for nebulae illuminated by a star, different data sets in the optical wavelength and in the UV wavelength ranges indicate a power law decrease of the surface brightness with angular distance to the illuminating star. Witt [18,19]) finds an exponent of 1.5. Zagury [22] finds 2. As it is shown in the latter paper, the quick decrease of the surface brightness with angular distance to the star confirms a strong forward scattering phase function. The power law dependence of the surface brightness on angular distance to the star also shows that the illuminating source must be close to the nebula, as noted in section 4.

Let  $\varphi$  be the angle of scattering,  $\theta$  the angular distance of a nebula from its' illuminating star,  $d$  and  $D$  the respective distances of the star to the nebula and to the observer. These notations correspond to the figure 8 of paper I. We have  $\varphi = (D/d)\theta$  and  $\varphi > \theta$  since  $D > d$ . From figure 8 of paper I, it is clear that, if  $\theta$  and the distance earth-nebula are kept constant,  $\varphi$  decreases when  $D$  increases. Because of forward scattering, for a given and constant strength of the radiation field at the cloud location, the nebula surface brightness will increase when the star is moved away. Hence, for a given sensitivity of the observation and for a constant value of the radiation field at the cloud location, the angular distance  $\theta$  from the source at which a nebula can be detected increases when the star is far away. The maximum angular distance at which the nebula can be observed with a given sensitivity and strength of the radiation field at the cloud location is obtained for a star at infinity. In this case  $\theta = \varphi$  and  $D/d = 1$ .

It was noted in paper I that Polaris may illuminate MCLD123.5+24.9 and have a negligible contribution to cloud heating. This is possible because the star will have its' light efficiently scattered due to the small angle of scattering while the heating of the dust by Polaris can be small compared to the radiation field due to all the stars. Geometry can favor scattering of the light of a particular star while heating is sensitive to the integrated radiation field.

## 7 The surface brightness of a nebula illuminated by a large number of point sources

The illuminating source is supposed to be all the background stars. Because of forward scattering stars within a certain angle  $\theta_{max}$  from the direction of the nebula will make a major contribution to the cloud surface brightness. Pixels

looking outside the cloud and in between 2 stars will receive no power, while pixels looking at the cloud will receive the light diffused by grains inside the cirrus.

If stars are evenly distributed in the sky, at least within  $\theta_{max}$  from the direction of the cloud, photons scattered once will create an isotropic radiation field (within  $\theta_{max}$ ), so that further scatterings will not increase the cloud surface brightness (case iii of section 5). The single scattering approximation proposed in paper I can be applied. With an average illumination by unit solid angle  $\sigma$ , due to stars within  $\theta_{max}$ , in the cloud vicinity, the cirrus surface brightness will remain proportional to  $\sigma$  and will not depend on the phase function:

$$S = \sum_{stars} (g(\varphi_{\star}) \omega \tau e^{-\tau} F_{\star}) \quad (1)$$

$$= \sigma \omega \tau e^{-\tau} \int_{\varphi} 2\pi g(\varphi) d\varphi \quad (2)$$

$$= \sigma \omega \tau e^{-\tau} \quad (3)$$

The surface brightness reaches its maximum for  $\tau = 1$ :

$$S_{max} = 0.37 \omega \sigma \sim 0.2 \sigma, \quad (4)$$

with  $\omega = 0.6$ . If units of mag per unit solid angle are adopted:

$$S_{max} = m_{\sigma} + 1.7, \quad (5)$$

with  $m_{\sigma}$  the surface brightness of the background sources.

High latitude cirrus are close to the earth, compared to the stars' scale-height ( $\sim 400$  pc). For the purpose of calculation, we can suppose that the radiation field seen by an HLC is the same we see on earth and estimate  $\sigma$  from galactic models such as the Besançon Galactic model ().

## 8 An example: the illumination source of MCLD123.5+24.9

In paper I, illumination of MCLD123.5+24.9 was studied under the assumption that the field is illuminated by Polaris. The maximum surface brightness over the field, above the absorbed region mapped by Falgarone et al. [2],  $\sim 0.032 \pm 0.003$  MJy/sr (24 mag/arcsec<sup>2</sup>) in the  $R$  band, can be explained by illumination by Polaris, even if the star does not contribute to the Polaris Flare heating. Paper I bases itself on the hypothesis that Polaris is behind the



cirrus. This hypothesis, although credible, has not yet been proven. If Polaris was in front of the Polaris Flare, illumination of MCLD123.5+24.9 by the star would probably have to be reviewed. Another explanation, for instance illumination by all the background stars, will need to be considered.

From the Guide Star Catalog and Besançon Galactic model, assuming the cirrus is illuminated by the same distribution of stars we see from Earth,  $\sigma_R$  is found to be  $\sigma_R \sim 0.1 \text{ MJy/sr}$  or  $\sim 23 \text{ mag/arcsec}^2$  in MCLD123.5+24.9 direction. If the field was illuminated by all the background stars, the expected maximum  $R$  surface brightness over the field would be  $0.02 \text{ MJy/sr}$  or  $24.5 \text{ mag/arcsec}^2$  (equation 4), close to what is observed. The surface brightness of the very low column density medium, of average extinction  $A_V \sim 0.5$  ( $A_R \sim 0.37$ ), in which MCLD123.5+24.9 seems to be embedded (see paper I), will be  $\sigma\omega\tau e^{-\tau} = 0.015 \text{ MJy/sr}$  (equation 3). The difference between the 2 values,  $0.005 \text{ MJy/sr}$ , is the quantity which should be compared to the  $0.032 \text{ MJy/sr}$  found on the  $R$  image. If this interpretation is true, background stars do not provide the luminosity to account for MCLD123.5+24.9 optical emission.

For constant albedo and phase function, the maximum brightnesses over the field in different bands, assuming that they are reached at some (not necessarily the same for each band) pixel in the field, should scale like the source radiation field intensities. In MCLD123.5+24.9's case:  $SB_{B,max}/SB_{I,max} \sim (0.6 \pm 0.1)$  and  $SB_{R,max}/SB_{I,max} \sim 1$ . The colors of Polaris are  $F_B^0/F_I^0 \sim 0.5 - 0.7$ ,  $F_R^0/F_I^0 \sim 1$  (paper I, table 1), in accordance with the previous values. For the background sources model, we have  $\sigma_{B,max}/\sigma_{I,max} \sim 0.5$ ,  $\sigma_{R,max}/\sigma_{I,max} \sim 0.89$ . If stars with magnitudes of less than 6 were included, both colors would be diminished.

This argumentation is nevertheless model dependent. I do not feel it is conclusive so the choice remains between the cirrus being in front of Polaris and illuminated by it, or being behind Polaris and illuminated by all the background stars. In the latter case its distance to the sun should be greater than 130 pc. More definitive conclusions should come from the comparison of spectroscopic observations of MCLD123.5+24.9 and Polaris or by precise determination of the cloud distance from the sun.

## 9 Second example: a cirrus illuminated by the LMC?

In 1955, G. de Vaucouleurs (de Vaucouleurs [1]) published a study of the LMC. Plate II and figure 2 of de Vaucouleurs' paper show a long filament extending  $10^\circ$  far, West and North, from the LMC. The filament surface brightness ranges between  $25 \text{ mag/arcsec}^2$  and  $27 \text{ mag/arcsec}^2$  at its most distant part. Figure ??

reproduces de Vaucouleurs image along with the IRAS 100  $\mu\text{m}$  image of the same region.

Originally (de Vaucouleurs [1]) this feature was interpreted as a possible spiral arm of the LMC, though later detailed searches revealed a puzzling absence of stars (W. Kunkel, private communication). Comparison with the IRAS 100  $\mu\text{m}$  image (figure ??) shows it is in fact part of a large high latitude galactic cirrus. Its distance to the sun is estimated to be between 70 pc (Wang & Yu [17]) and 200 pc (Penprase et al. [13]).

The IRAS 100  $\mu\text{m}$  surface brightness of the filament does not exceed 6 MJy/sr and decreases toward its northern extremity. This decrease can be interpreted as a decrease of column density along the line of sight. It may also be attributed to the attenuation of the heating because it coincides with the decrease of the ambient ISRF: the filament extends toward high galactic latitudes, from  $b = -33$  to  $b = -45$ .

Two radiation fields can be thought of to explain the filament optical brightness.

One is background stars. From the Besancon model of our galaxy, the surface brightness of the background stars at optical wavelengths is of order 30 mag/arcsec<sup>2</sup> at the LMC position, and decreases with increasing latitude. According to equation 5, scattering of the background starlight by dust in the cirrus will give a surface brightness of 30 mag/arcsec<sup>2</sup> or more. If so, background stars are not luminous enough to account for the cirrus optical brightness.

The only luminous object of the region is the LMC. The LMC has an apparent magnitude  $B_0^T \sim 0.9$  mag and a surface brightness of  $m'_{25} \sim 22$  mag/arcsec<sup>2</sup> (Third Reference Catalogue of Bright Galaxies, de Vaucouleurs 1991, ). Correction for extinction by the cirrus will decrease these values. In the LMC immediat vicinity, equation 5 shows that illumination by the LMC will explain the filament brightness. Assuming a decrease of the brightness as  $\theta^{-2}$  at most, section 6, the expected decrease of the surface brightness of the filament over 10° (corresponding to the extent of the filament) will be at most 5 mag/arcsec<sup>2</sup>, which is compatible with the observations. The large area over which the LMC filament was observed, much larger than observed for nebulae illuminated by a close star, agrees with the discussion of section 6 on the angular extent up to which the scattered emission of a nebula is detectable.

## 10 Illumination of high latitude clouds by the ISRF

The ISRF from one direction comprises the light from the stars in that direction and the diffuse galactic light (DGL) which is the starlight scattered by interstellar grains. As indicated in a previous paper (Zagury, ‘Is there ERE at high galactic latitude?’, submitted), and because grains forward scatter light, DGL in one direction can logically be attributed to be the light of background stars scattered by dust embedded in the nearby cirrus on the line of sight.

Contrary to the direct starlight, DGL cannot contribute to the illumination of a cirrus. This is a straightforward consequence of section 7 (second paragraph). The maximum surface brightness of a cirrus due to the illumination by background stars is given by equation 4 of section 7: if there is no bright star in the vicinity of the cirrus its’ surface brightness is at most 20% of the background stars surface brightness. Since the surface brightness of background stars and galaxies decreases with increasing latitude, we can expect an average decrease of the cirrus’ surface brightness with increasing latitude. Such a decrease is observed, as shown by the studies of Toller [16] and of Gordon et al. [3]. As expected it is proportional to the decrease of starlight.

Concerning the specific case of the high latitude cirrus detectable on the Palomar plates, with a brightness level above average, the distribution of Palomar HLN’s all over the sky, with no evident correlation between surface brightness and galactic latitude, along with the much higher optical emission of HLN’s, may require the presence of a luminous object close to the cloud, as suggested for MCLD123.5+24.9 (paper I and section 2.3) and for the LMC filament (section 9).

## 11 The red color of the nebulae

Why should red areas in the sky act as emitting regions? After all, the sky (on earth) is blue in most cases, but the horizon may be red at sunset or sunrise. No one will ever claim there are crystalline nano particles of pure silicon (Witt [20]) or any other kind of emitting particles which luminesce at those particular times of the day. The red color of the sky comes from the increase of column density crossed by light when the sun rises or descends at the horizon. Why shouldn’t Lynds’ red nebulae, similarly and unless they are proved to be HII regions, be the consequence of variations in column density?

The  $10' \times 10'$  red feature of MCLD123.5+24.9, mapped by Falgarone et al. [2] in molecular lines is seen in absorption and totally extinguished on the blue image (section 2.3 and paper I). The high column densities and densities found in this

area confirm the link between red nebulae and high column density regions. In paper I we have explained the color variations of the nebula by variations of the column density and normal scattering properties of the grains. We have shown that there was no need for an additional component of red light created within the nebula.

The excess of red emission Guhathakurta & Tyson [4] and Guhathakurta & Cutri [5] found for nebulae similar to MCLD123.5+24.9 relies on a comparison of the nebulae color and the color of the galactic plane. It assumes the nebulae are illuminated by the galactic plane, which is difficult to accredit (section 4). The conclusion of both papers, that an additional ERE emission was necessary to justify the color of the nebulae, is now questionable. The Guhathakurta & Tyson [4] paper further assumes isotropic scattering to discard nearby stars as possible illuminating sources of the nebulae. Forward scattering will potentially allow at least one star for the illumination of each of the four fields (see figure 7 in Guhathakurta & Tyson [4]). This will of course completely modify their analysis as well as their conclusions. It follows, and unless more precise studies will prove the contrary, that no up to date observation implies another process than scattering to explain the color of high latitude clouds.

## 12 Conclusion

Complementary sets of data were compared to obtain a better understanding of the relation between nebulae and their illuminating source. The paper has focused on high latitude nebulae for which the source of light is more easily identified, but there is little doubt that the results gained for high latitude clouds still apply closer to the galactic plane.

The existence of a large number of high column density regions which are extinguished on the Palomar plates shows that the contribution of the galactic plane to the illumination of the infrared cirrus is negligible. It also implies that interstellar grains scatter light in forward direction, a property first uncovered by Henyey & Greenstein [6].

The illuminating source of a high latitude cloud must be behind the cloud and at close angular distance from it. It must present some anisotropy. It can be either the background stars in the direction of the cloud or a nearby star which dominates the radiation field over the directions close to the cloud line of sight.

As noted in paper I, a particular star can be responsible for the cloud optical emission without giving significant contribution to the heating of the cloud. This is because background stars close to the cloud line of sight have their

light efficiently scattered in the direction of the observer while stars from all directions contribute to the heating of the cloud. For a given intensity of the radiation field at the cloud position, the surface brightness of the cloud increases with the distance of the star from the cloud. This property may explain the large extent of a filament close to the LMC, detected at optical wavelengths by de Vaucouleurs [1]. Both its' surface brightness and the spatial extent of the emission would agree with illumination by the LMC.

When the scattered light cannot be attributed to an individual (eventually a few) star the surface brightness of the cloud will be at most 20% of the surface brightness of the background stars. The radiation field created by the scattering of the light from the background stars can not produce illumination of another cloud: DGL will not induce an increase of the surface brightness of high latitude clouds.

A precise determination of the illuminating source of a nebula is necessary before reaching any conclusion concerning its' color. The red color of some nebulae can be explained by higher column densities than in blue nebulae. Up to date observations do not seem to be able to prove the existence of any other process than scattering to explain the color of high latitude nebulae.

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